Taxing Externalities: Revenue vs. Welfare Gains
with an Application to U.S. Carbon Taxes

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Abstract

This paper asserts that when evaluating the desirability and political feasibility of an externality correcting tax, the ratio of the welfare gains to tax revenue should be an object of interest. While clearly important from a political economy perspective, the fact that this comparison might matter is somewhat of a “blind spot” in most economic analyses, for it plays virtually no role when economists recommend taxes to internalize externalities. The reason is that tax revenue is assumed to be welfare neutral. But is this assumption always reasonable? While political debates often revolve around this question, shouldn’t it matter if the tax revenue is orders of magnitude larger or smaller than the welfare gain? A simple model shows how the ratio of the welfare gain to tax revenue is increasing in the marginal external costs, yet decreasing in the size of the market and the equilibrium responsiveness to the tax. The wide range of potential results is illustrated with an application of carbon taxes to different fuels in the United States. For example, assuming a social cost of carbon (SCC) and a carbon tax equal to $50 per tonne, the central estimates imply ratios of 12.1 for coal, 0.36 for natural gas, 0.05 for diesel, and -0.05 for gasoline. When all four fuels are combined, the ratios indicate a more proportional balance between welfare gains and tax revenue, with overall estimates ranging between 0.7 and 2.8. The paper concludes with a general appeal for economists to pay more attention to the relative magnitudes of efficiency gains and tax revenue when analyzing and advocating for externality correcting taxes.

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1 Introduction

There is perhaps no concept more fundamental to the field of environmental economics than that of Pigouvian taxes. When confronted with an externality problem—regardless of whether it is local in nature (e.g., a nuisance between neighbors) or global in scope (e.g., climate change)—economists can be relied upon to deliver a policy recommendation about the need to get prices right, typically through Pigouvian taxes. By internalizing marginal external costs, Pigouvian taxes calibrate private incentives to implement the socially efficient level of market activity (Pigou 1920). Yet, despite the primacy of externality correcting taxes among economists, there are relatively few instances of their implementation in practice.

A leading explanation for why is that people—and therefore political leaders—simply dislike taxes. In response, economists often express frustration and assert that the problem is merely one of communication. They emphasize that tax revenue is itself not a cost: it can be returned lump-sum or used to provide public goods; unlike revenue raised from other taxes, it is distortion free when correcting an externality; and revenue neutrality is possible by reducing other distortionary taxes, which in turn can provide additional benefits, i.e., a “double dividend” (see Goulder 1995). While theoretically well-founded, these arguments often fail to resonate in practice because they sidestep potentially legitimate questions and concerns about tax revenue and the role of government, focusing instead on the more comfortable territory of economic efficiency.

The separation of questions about economic efficiency and tax revenue produces a foundation of theoretical results, yet the partition is difficult to maintain when it comes to policymaking in the real world.¹ This observation provides the starting point for the present paper that aims to highlight the importance of comparing the magnitude of welfare gains and tax revenue when it comes to advocating for, and understanding opposition to, externality correcting taxes. Beyond making a general, conceptual point, the paper

¹ The basic idea here is consistent with the caricature that economists tend to care about triangles, whereas everyone else cares about rectangles. The shape distinction is based on the way that welfare gains are usually measured as triangles in linear graphical analyses, and tax revenue is usually measured as rectangles.
provides an empirical application to carbon taxes in the United States, where comparisons are made across fossil fuels and economy wide to illustrate a range of potential results.

The fact is that economists rarely make comparisons between these two measures—welfare gains and tax revenue—when analyzing and recommending externality correcting taxes. The reason is that tax revenue is typically considered welfare neutral (in both partial and general equilibrium analyses), so comparing revenue to welfare gains is an “apples-to-oranges” comparison from a standard welfare economics perspective. But it is precisely this “apples-to-oranges” comparison that drives much of the debate about externality-motivated taxes in the real world. Those with a primary concern about the externality focus on the welfare gains of imposing a tax, whereas those categorically opposed to new taxes often mount the opposition. The latter group rejects the basic assumption that tax revenue is welfare neutral; they view it more as a cost or mechanism for unwelcome transfers, and they often focus on government inefficiency and the incidence on producers and consumers.

In recognition of these tradeoffs, the fundamental assertion in this paper is that the ratio of the welfare gain to the tax revenue should be an object of interest when evaluating the desirability and political feasibility of an externality correcting tax. This holds when evaluating a policy at the optimal tax rate or at any rate that seeks to address some portion of an externality. At the most basic level, the ratio provides useful information about whether a particular policy generates welfare gains that might be a tiny fraction of the tax revenue, or whether the welfare gains might be orders of magnitude larger. While clearly important from a political economy perspective, the fact that this consideration might matter is a “blind spot” in typical economic analyses, for it plays virtually no role when economists recommend taxes to internalize externalities.

There are many reasons for why the ratio of the welfare gain to the tax revenue of a particular policy is informative. Absent a need to raise revenue, it is reasonable to assume that externality correcting tax policies with a lower ratio are less politically desirable, feasible, or both. When the efficiency gain is exceedingly small compared to the tax revenue, is the policy really worth it without a compelling need for revenue? It is efficient given the assumption of tax revenue’s welfare neutrality, but whether this assumption
holds in practice becomes increasingly important the smaller the ratio. Taking account of the ratio therefore has the advantage of clarifying the relative importance of revenue concerns and assumptions vis-à-vis efficiency gains when considering corrective taxes. Lower ratios might reasonably prompt more questions about how exactly the revenue will be used and how efficient is the administrative capacity. One might even interpret the ratio as a scaled measure of the potential vulnerability to regulatory capture (Dal Bó 2006) over how the tax revenue will be spent, that is, lower ratios have greater vulnerability for comparable welfare gains. Finally, when raising revenue is an objective, the ratio is informative about which externalities could be targeted to produce greater welfare gains (i.e., those with greater ratios).

To further motivate some of these ideas, the next section of the paper briefly describes selected examples of Pigouvian taxes from the literature. A general observation is that basic information about tax revenue is rarely even reported because of the sole emphasis on efficiency. It is nevertheless possible to back out estimates in many cases, and doing so indicates that economists sometimes advocate for policies where the ratio of the welfare gain to tax revenue is exceedingly small. Moreover, because the relative magnitudes of welfare gains to tax revenue are not considered, economists often miss opportunities to provide information that can inform choices among policy alternatives.

Section 3 develops a basic framework for deriving ratios and identifies factors that affect magnitudes. The ratio of the welfare gain to the tax revenue is decreasing in the size of the market, decreasing in the market’s equilibrium responsiveness to changes in the tax (which accounts for both supply and demand elasticities), and increasing in the magnitude of the marginal external costs. While not one of these factors is typically taken into account when economists recommend corrective taxes, the ratio of the welfare gain to tax revenue does have an interpretation similar the that of the marginal value of public funds (MVPFs) (Hendren 2016; Hendren and Spring-Keyser 2020). The similarities and differences are discussed later in the paper along with a comparison to the even more familiar measures of marginal excess burden (MEB) (Harberger 1964) and the marginal cost of public funds (MCPF) (Stiglitz and Dasgupta 1971; Atkinson and Stern 1974).
Sections 4 and 5 provide empirical estimates of ratios for implementation of a carbon tax in the United States. While much attention has focused on carbon taxes to avoid the costs of climate change and to raise tax revenue, little attention has focused on the relative magnitudes of these two impacts. The analysis builds on the model first developed in Kotchen (2021) and considers four fuels—natural gas, coal, gasoline and diesel—separately and combined. While all ratios are sensitive to parameter assumptions, of particular interest here is how heterogeneity of the results across fuels exemplifies the different possibilities that the general framework is intended to illustrate.

Assuming a social cost of carbon (SCC) and a carbon tax equal to $50 per tonne, the central estimates imply ratios of the welfare gain to tax revenue of 12.1 for coal, 0.36 for natural gas, 0.05 for diesel, and -0.05 for gasoline. Coal has the highest ratio by a wide margin because of its substantially larger marginal external costs and greater equilibrium elasticity. Natural gas represents an intermediate case, while the magnitudes for diesel and gasoline are exceedingly small and even negative. The latter results are driven by the large market sizes, the relatively small equilibrium elasticities, and the presence of preexisting taxes. In the case of gasoline, imposing a carbon tax over and above existing federal and state excise taxes results in a marginal tax rate that exceeds the marginal social costs due to climate damages and local pollution.

When all four fuels are combined via a uniform carbon tax, the ratios indicate a more proportional balance between welfare gains and tax revenue. Continuing to assume $50 per tonne for both the SCC and the carbon tax, the overall ratio ranges between 0.7 and 1.03 depending on the elasticity scenario. This means that somewhere between seventy cents and one dollar of social net benefits are created for each dollar of tax revenue. Importantly, this is not a benefit-cost comparison precisely because the tax revenue is not a cost to society. But a striking interpretation, potentially in support of the policy, is that a ratio greater than one implies that imposing the tax would pass a benefit-cost test even if all the tax revenue were “burned” and not used to generate additional social benefits. The ratios are even greater if the carbon taxes for each fuel are calibrated to only take effect when they exceed preexisting excise taxes, in which case the overall ratio ranges between 0.88 and 2.82, with a central estimate of 1.84. The final part of Section 5 compares results
of the model to those of more detailed and computationally intensive models that are part of the Stanford Energy Modeling Forum, and these comparisons show a high degree of externality validity.

Section 6 concludes with a discussion of the key findings and an appeal to economists to pay more attention to revenue when analyzing and advocating for externality correcting taxes. The virtue of Pigouvian-type taxes hinges critically on the assumption of tax revenue’s welfare neutrality—both real and perceived—and more transparency about the relative magnitudes of welfare gains and tax revenue will help clarify how important these assumptions are in particular applications. A focus on the comparison will also make many economists more aware of whether their tax-policy recommendations should really be thought of first and foremost as promoting economic efficiency or as a mechanism for raising and dispensing revenue. Providing such basic information may also help bridge the gap between economic analyses and the political economy of implementation.

2 Motivating Examples

Let us now turn to selected examples of externality correcting taxes from the literature. Each one is intended to illustrate different ways in which policy evaluation would be aided with additional information about the ratio of the welfare gain to tax revenue.

2.1 Airplane noise

The 1990 Airport Noise and Capacity Act (ANCA) in the United States mandated the elimination of certain aircraft because of the noise externality their engines imposed on home owners near airports. Morrison et al. (1999) provide a benefit-cost analysis of the regulatory requirement and find that the present value benefits of $5 billion fall short of the costs of $10 billion. The authors then analyze and advocate for what would have been an alternative regulatory approach, implementation of a Pigouvian tax. They estimate that an efficient tax would have generated a net welfare gain of $0.013 billion per year, which
translates into present value net benefits of $0.184 billion.\textsuperscript{2} What is not reported, or even mentioned, in the paper is the revenue that imposing the tax would generate. It is nevertheless possible to make the calculations that yield a present value of tax revenue equal to $12.15 billion.\textsuperscript{3} The result is a ratio of the welfare gain to tax revenue that is exceedingly small: 0.015, which implies an average of 1.5 cents of benefits for each dollar of tax revenue.

The Pigouvian tax is by definition efficient assuming welfare neutrality of the tax revenue, and on these terms, the tax may be preferred to the ANCA mandate. But the fact that only 1.5 cents of benefits are created for each dollar of tax revenue should certainly play a role in debate about whether the tax policy is a preferred approach. It would only take a small amount of administrative cost (just over 1.5 percent of the revenue) for the tax to be inefficient. Moreover, rather than a comparison to the inefficient mandate of the ANCA, the more relevant comparison is likely to be an efficient mandate that induces behavior consistent with the Pigouvian tax. This would produce the same welfare gain without implementing what is effectively a revenue raising policy in comparison to the relatively small net benefits. While the preferred policy approach is certainly open for debate, the objective here is to make two observations: a) economists, perhaps even unknowingly, sometimes advocate for externality correcting taxes when the ratio of benefits to tax revenue is exceedingly small, and b) the information necessary to make such a comparison transparent is often not reported because of the sole focus on efficiency.

2.2 \textit{Pollution taxes in the electricity sector}

Griffin (1974) provides an early analysis of pollution taxes in the U.S. electricity sector that illustrates a further way in which the ratio of welfare gains to tax revenue can inform choices among policy alternatives. He considers a tax on sulfur oxide emissions

\textsuperscript{2} Consistent with other calculations in Morrison et al (1999), this assumes a 7-percent discount rate and a flow of benefits and costs in perpetuity.

\textsuperscript{3} Using the approach and estimates reported in Morrison et al. (1999), the procedure is as follows. Average industry revenue is $88.7 billion, and private marginal cost is $13,145, which they assume is equal to price. The marginal external cost equal to the tax is $127, and this implies an assumed mark-up of one percent. The initial quantity is 6,747,813 flights (equal to $88.7B/$13,145). Then using the assumed demand elasticity of -0.7, the after-tax quantity of flights decreases to 6,700,578. Multiplying this quantity by the tax yields annual revenue of $0.851 billion, which translates into a comparable present value of $12.15 billion.
consistent with proposed legislation at the time. The analysis considers three different tax rates (10, 15, and 20 cents per pound of sulfur) and a range of estimated control costs across 9 difference scenarios. While the net welfare effects are explicitly reported and discussed across scenarios as being the “critical variable to economists (p. 683),” there is also mention of how “the politician is likely to be more concerned with the distributional effects of the tax (p. 683).” However, not mentioned or reported is the tax revenue itself.

Backing out estimates of the tax revenue based on information provided, one finds that the ratios vary dramatically across scenarios: from of a low of 0.25 to a high of 9.96. That is, depending on the scenario, the tax policy produces a welfare gain of between 25 cents and $10 per dollar of tax revenue. But perhaps of even more interest is a comparison across scenarios with the same compliance cost assumptions and different tax rates. In the three low-cost scenarios, the net welfare gain is roughly constant across the three tax levels, ranging between $42 and $43 billion over a 10-year period, but the tax revenue increases with the tax rate. In particular, the estimates over the 10-year period are $4.22 billion at 10 cents, $5.58 billion at 15 cents, and $7.4 billion at 20 cents, and the corresponding ratios are 9.95, 7.63, and 5.76. While all the ratios might seem relatively favorable, the differences among them is policy relevant. With welfare benefits roughly equal across scenarios, the preferable option is likely to depend on whether raising revenue is considered desirable or not, yet this observation is not even apparent with standard reporting that does not report tax revenue.

2.3 A congestion charge

In 2003, the city of London began implementing a daily charge on driving and parking in designated zones and at designated times to reduce traffic congestion. An additional aim of the policy was to establish a source of tax revenue earmarked for spending on London’s public transportation. Unlike the previous examples, this is a policy

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4 Table 2 in Griffin (1974) reports the average annual emissions over the a 10-year period. These emissions multiplied by the tax rate and 10 years in each scenario produces estimates of tax revenue that are comparable with the 10-year estimates of the net welfare gain.
with the dual aims reducing an externality and raising tax revenue. The information is therefore more readily available for comparing the magnitude of these two impacts.

Leape (2006) provides an *ex post* analysis of the congestion charge that draws on other studies and provides new estimates. Annual net benefits in the early years were estimated at £67 million, and the revenues were less than expected at £63 million and £97 million in the first and second year, respectively. These estimates imply annual ratios of 1.06 and 0.69, and this provides a sense of the relative magnitudes in a case where real policy was focused on both the numerator and denominator. Interestingly, an unexpected feature of the policy was a significant degree of noncompliance, and enforcement through penalty notices was found to raise additional revenue of £70 million, resulting in lower ratios of 0.5 and 0.4. In this case, lower ratios are not necessarily a disadvantage given the aim of raising revenue, but the importance of noncompliance and enforcement does highlight the need to consider administrative burdens of collecting revenue that will ultimately affect both the numerator and denominator.

### 2.4 A soda tax

The final example is a sin tax on sugar-sweetened beverages in the United States. Allcott et al. (2019) solve for the optimal tax that accounts for both externalities and internalities, and their estimates range between 1 and 2.1 cents per ounce, depending on the specification. The net welfare gain for their baseline scenario is $2.4 billion per year. Once again, the tax revenue is not explicitly reported in the paper, but making the calculation for the baseline scenario yields an estimate of $6.7 billion per year. The ratio of the welfare gain to tax revenue is therefore 0.36, and it is worth noting that the externality (increased public health care costs) and the internality (consumer psychological biases) contribute to the welfare gain in roughly equal proportions.

Beyond providing a non-environmental example, the soda tax is useful for illustrating an additional point: the increased focus on revenue as part of distributional

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5 The per capita tax revenue in shown in Figure IX of Allcott et al. (2019), although the number itself is not reported. Through personal communication, the estimate was found to be $21.52 per capita, which is then multiplied by 311 million adult equivalents.
analyses. Allcott et al. (2019) consider the welfare consequences of the policy at different levels of income assuming equal lump-sum redistribution of the tax revenue. This type of analysis is increasingly considered in research on externality correcting taxes as interest has grown in whether such policies are regressive or progressive, or have other distributional impacts of potential concern.\(^6\) While this exemplifies one way in which greater attention is focused on tax revenue, it does not address the more overarching concern here about the relative magnitudes of the overall welfare gain to the tax revenue. Yet such a comparison itself highlights how important redistribution assumptions might be for the regressivity or progressivity of a externality correcting tax.

3 Conceptual framework

This section develops a straightforward framework to show the relationship between the welfare gain and tax revenue for an externality correcting tax. The aim is to formally define the ratio, identify factors that affect its magnitude, consider a standard special case, and relate the measure to others commonly employed in public economics.

3.1 Basic setup

Consider a market for good \(Q\). Let \(D(Q)\) denote inverse demand and \(S(Q)\) denote inverse supply. The setup admits the possibility for a preexisting excise tax on good \(Q\) equal to \(\tau \geq 0\). We can write the equilibrium quantity as function of the tax such that \(Q(\tau)\) satisfies the market clearing condition \(D(Q) = \tau + S(Q)\). The exchange of \(Q\) also generates an externality, where \(m(Q)\) denotes the marginal external costs with \(m'(Q) \geq 0\). It follows that the efficient quantity, denoted \(Q^*\), will satisfy \(D(Q^*) = m(Q^*) + S(Q^*)\).

Now consider the possibility for new tax \(\lambda\) on each unit of \(Q\) such that the overall tax is \(\tau + \lambda\). The new equilibrium quantity is \(Q(\tau + \lambda)\) that satisfies \(D(Q) = \tau + \lambda + S(Q)\). The efficient new tax is \(\lambda^* = m(Q^*) - \tau\), where \(\lambda^* + \tau\) is the familiar Pigouvian tax

\(^6\) Examples of papers that focus on the distributional impacts of carbon taxes (which are the focus later in this paper) combined with revenue redistribution include Grainger and Kolstad (2010), Metcalf (2019), Williams et al. (2014) and Goulder et al. (2019). Other studies also consider how the expenditure of tax revenue affects political support (e.g., Kotchen et al. 2017; Klenert et al. 2018; Carattini et al. 2018).
rate. Note that, in general, $\lambda^*$ could be positive or negative (i.e., a subsidy) depending on the size of the preexisting tax.

### 3.2 The ratio

We can now turn to the change in welfare and tax revenue given implementation of a new tax. For any given tax rate $\lambda$, the change in welfare can be written as

$$\Delta W(\lambda) = \int_{Q(\tau)}^{Q(\tau + \lambda)} m(Q) - [D(Q) - S(Q)]dQ.$$  

(1)

The first term is the change in total external costs, and the second term in brackets is the net foregone private surplus. Notice that while the expression is fully general for any new tax rate $\lambda$, the level that maximizes the expression is the Pigouvian level $\lambda^*$. \(^7\) The change in tax revenue from any given $\lambda$ is

$$\Delta TR(\lambda) = (\tau + \lambda)Q(\tau + \lambda) - \tau Q(\tau),$$

(2)

which consists of the total revenue raised at the new equilibrium quantity and new tax rate minus the revenue raise at the initial equilibrium quantity and initial tax rate.

The measure of central interest here is the ratio of the change in welfare over the change in tax revenue at any level (i.e., not necessarily the efficient level) of the new tax rate $\lambda$:

$$R(\lambda) = \frac{\Delta W(\lambda)}{\Delta TR(\lambda)} = \frac{\int_{Q(\tau)}^{Q(\tau + \lambda)} m(Q) - [D(Q) - S(Q)]dQ}{\lambda Q(\tau + \lambda) - \tau [Q(\tau) - Q(\tau + \lambda)]},$$

(3)

where the denominator has been rearranged a bit to facilitate interpretation. Three results follow immediately from equation (3) about the factors that contribute to having a larger or smaller ratio, and each result applies holding the other factors constant.

**Result 1.**—The ratio is increasing with a greater marginal externality, $m(Q)$. This increases the welfare gain of reducing the quantity for any given tax without affecting tax revenue. Note that the statement holds for a given tax $\lambda$ and does not necessarily hold for

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\(^7\) To see this formally, differentiate equation (1) using Leibniz Rule, which yields the first-order condition $[m(Q) - D(Q) + S(Q)]dQ(\tau + \lambda)/d\lambda = 0$. This is satisfied at $Q^*$, which sets the term in brackets equal to zero and is the equilibrium consistent with $\lambda^* = m(Q^*) - \tau$. 

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taxes that adjust to the size of the marginal externality (e.g., a Pigouvian tax), as these would affect tax revenue as well, thereby changing both the numerator and denominator.

**Result 2.**—The ratio is increasing with greater responsiveness of the equilibrium quantity to implementation of the new tax, \( Q(\tau) - Q(\tau + \lambda) \). This result applies unambiguously provided that the new tax is not large enough to cause the combined tax to exceed the Pigouvian level, that is, when \( \lambda \leq m(Q^*) - \tau \) at both the initial and new tax level. If this condition holds, increasing the difference \( Q(\tau) - Q(\tau + \lambda) \) increases the numerator and decreases the denominator, resulting in a higher ratio.\(^8\) Note that the market responsiveness is itself increasing in both the demand and supply elasticity, each of which themselves would contribute to a greater ratio.

**Result 3.**—The ratio is decreasing in the size of the market. To see this result, let us measure the size of the market based on the quantity exchanged and assume a fixed level of market responsiveness to a given level of the new tax. This means that we can characterize the size of market with the magnitude of \( Q(\tau + \lambda) \).\(^9\) Referring back to equation (3), we see that an increase in the size of the market only has the effect of increasing the denominator, as the difference between \( Q(\tau) \) and \( Q(\tau + \lambda) \) is held fixed. This means that, all else constant, a greater market size decreases the ratio, and this is intuitive because a greater market size implies more units upon which the new tax is levied.

### 3.3 The linear special case

A special case with linear functions, which is the standard textbook case, is helpful to build further intuition and establish some baseline results. Assume inverse demand takes the form \( D(Q) = \alpha - \beta Q \), and inverse supply is \( S(Q) = \gamma + \mu Q \). Assume further a constant marginal external cost \( m(Q) = \phi \). With this setup and a new tax level \( \lambda \), it is

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\(^8\) Although perhaps the less interesting case, if the new tax where to push the combined tax above the Pigouvian level, greater responsiveness would decrease the numerator, as the foregone private surplus would be growing at a faster rate than the reduction in external costs. In this case, the overall effect on the ratio would depend on whether the numerator is decreasing at a faster or slower rate than the denominator, which is generally indeterminant.

\(^9\) One could also use \( Q(\tau) \). Using the quantity before or after implementation of the new tax is possible because of the assumption of a constant difference between the two.
straightforward to solve for the reduction in external costs and the foregone private surplus. The difference between these two changes is the overall change in welfare consistent with equation (1):

$$
\Delta W(\lambda) = \frac{\phi \lambda}{\mu + \beta} - \frac{\tau \lambda + \lambda^2 - \tau^2}{2(\mu + \beta)}
$$

$$
= \frac{2\phi \lambda - \tau \lambda - \lambda^2 - \tau^2}{2(\mu + \beta)}.
$$

(4)

Assuming the tax is set sufficiently low, this expression is the reduction in deadweight loss (DWL) associated with a given level of the new tax. Solving now for the change in tax revenue in equation (2) yields

$$
\Delta TR(\lambda) = \frac{\lambda(\alpha - \gamma - 2\tau - \lambda)}{\mu + \beta}.
$$

(5)

The ratio of interest is equation (4) over equation (5), which holds for any preexisting tax $\tau$ and any new tax $\lambda$. Because the ratio is cumbersome even for this linear, special case, it is helpful to narrow things even more, by assuming the most basic setup with no preexisting tax (i.e., $\tau = 0$). In this case, the ratio can be written as

$$
R(\lambda; \tau = 0) = \frac{2\phi - \lambda}{2(\alpha - \gamma - \lambda)}.
$$

(6)

Two of the three results highlighted above are immediately apparent. The first is that the ratio is increasing in the size of the marginal externality $\phi$ (Result 1). The second is that the ratio is decreasing in the size of the market, which can be measured as the difference between the vertical intercepts of demand and supply, $\alpha - \gamma$ (Result 3). It turns out in this linear special case, however, that the equilibrium responsiveness (Result 2) based on the slopes of demand and supply has no effect on the ratio. Although the result is not especially intuitive, examination of (4) and (5) shows why: the slope parameters show up only in the denominators of both expressions as $\mu + \beta$, and because they enter multiplicatively, any shifts that affect the sum will alter $\Delta W(\lambda)$ and $\Delta TR(\lambda)$ in the same proportion, resulting in no change to the ratio.

A final result to consider is a further special case of (6) where the tax is set not at any arbitrary level, but at the optimal (Pigouvian) level such that $\lambda = \lambda^* = \phi$. In this case, equation (6) simplifies further to
The fundamental insight of this expression is that the same results apply even when taxes are set optimally: the ratio is increasing in the marginal externality and decreasing in the market size, yet the market responsiveness has no effect in the linear special case.

### 3.4 Relation to other concepts

How is ratio of the welfare gain to tax revenue for externality correcting taxes related to other measures commonly used in public economics? A series of recent papers (Hendren 2016; Hendren and Sprung-Keyser 2020; Finkelstein and Hendren 2020) advance the notion of the marginal value of public funds (MVPF), which is broadly defined as the ratio of the marginal benefits of a policy change to the net marginal cost to the government. The MVPF is perhaps the most closely related concept, though its formulation and interpretation does have some differences with the ratio described here.

The MVPF is most naturally applied to policies that require government expenditures, where it is interpreted as the benefit per dollar of government spending for a particular policy. The MVPF can thus be used to target policies that maximize benefits per unit of government expenditure. In the case of an externality correcting tax, however, the welfare gain is generally associated with an increase in tax revenue rather than an expenditure. Hendren and Sprung-Keyser (2000) note the possibility for policies to have a negative net cost to the government, yet they interpret such cases as having an infinite MVPF, with the rationale that these policies “pay for themselves.”

Part of the contribution here is to show that with externalities, lumping all policies that “pay for themselves” in to the same category can over overlook important information.

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10 The MVPF has received recent attention because of its direct relation to estimation of causal effects in empirical studies. Yet the idea itself has been around for quite some time, as the authors of the recent papers readily acknowledge. Earlier papers that define the concept include Mayshar (1990) and Slemrod and Yitzhaki (2001).

11 It is worth noting that the MVPF defined by Hendren and Sprung-Keyser (2000) accounts for all behavioral responses (including those not in the policy targeted market) that might affect net expenditures. In contrast, the change in tax revenue developed here is a partial equilibrium approach that only accounts for changes in the regulated market. A more complete, though complicated, development of the ratio could account for these indirect effects.
For reasons already discussed, it is useful to know the relative magnitudes of the welfare gain and the tax revenue, and this information may also be useful for setting priorities among policies. To the extent there exists an aversion to raising tax revenue, the ratios identify which externality correcting taxes are ones that produce a greater welfare gain per dollar of revenue raised. And although the MVPF is formally developed as a marginal measure, the same ideas apply to non-marginal changes, where one would interpret the ratio as the average value of public funds for a particular policy. In parallel, the ratio developed in this paper is motivated for non-marginal changes to show the average welfare gain per unit of tax revenue, but it can also be used as a marginal measure if one considers incremental changes to the new tax λ.

Finally, the ratio in the present analysis and the MVPF are both based on a Marshallian rather than Hicksian measures of welfare change, and both do not take a stand on how the overall government budget is closed. This has the advantage of anchoring the analysis in more readily observable market data and behavioral responses. But it does cause them to differ from the familiar measures of the marginal/average cost of funds (MCF) (Stiglitz and Dasgupta 1971; Atkinson and Stern 1974) and the marginal/average excess burden (MEB) (Harberger 1964; Auerbach 1985; Auerbach and Hines 2002)—both of which are based on Hicksian (compensated) welfare measures. Hendren (2016) provides a detailed discussion of how the MEB and the MCF relate to the MVPF, and these discussions translate in applicability to the ratio of the welfare gain to tax revenue in the context of an externality correcting tax.

3 Carbon tax model and assumptions

Let us now turn from theory to application with implementation of a carbon tax in the United States. The analysis considers the markets for four different fossil fuels (natural gas, coal, gasoline, and diesel) separately and combined. In particular, the approach is to consider carbon taxes at different levels, along with a range of marginal external costs, to derive ratios of the welfare gain to tax revenue for each fuel individually and all four fuels
combined. The model and assumptions build on Kotchen (2021) and are briefly summarized in this section.12

3.1 The model

Supply and demand are of the constant elasticity functional form. Supply is $Q = Ap^\eta$ where $\eta > 0$, and demand is $Q = Bp^\varepsilon$ where $\varepsilon < 0$. The initial market price satisfies $p = p_b = p_s + \tau$, where $p_b$ is the price consumers pay, and $p_s$ is the price suppliers receive net of the preexisting tax. Market clearing implies $Q(\tau) = Bp_b^\varepsilon = Ap_s^\eta$, and this establishes prices as a function of the tax, written as $p_b(\tau)$ and $p_s(\tau)$. The initial equilibrium also enables estimation of the scale parameters $B = Q(\tau)/p^\varepsilon$ and $A = Q(\tau)/(p - \tau)^\eta$, which fully specifies both supply and demand.

With this simple and transparent setup, it is straightforward to solve for the way that implementing a new tax $\lambda$ alters the equilibrium quantity. Market clearing establishes the new prices $p_b(\tau + \lambda)$ and $p_s(\tau + \lambda)$, as described above, and the new equilibrium quantity will satisfy

$$Q(\tau + \lambda) = \left( \frac{p_b(\tau + \lambda)}{p_b(\tau)} \right)^\varepsilon Q(\tau) = \left( \frac{p_s(\tau + \lambda)}{p_s(\tau)} \right)^\eta Q(\tau).$$

(7)

This is the standard result that with constant elasticity, changes in quantity scale in the same proportion as changes in price, and this applies to both demand and supply. Using the second equality and substituting out the supply price, we have

$$\left( \frac{p_b(\tau + \lambda)}{p_b(\tau)} \right)^\varepsilon = \left( \frac{p_b(\tau + \lambda) - \tau - \lambda}{p_b(\tau) - \tau} \right)^\eta$$

(8)

This equation leaves only one unknown to solve for, $p_b(\tau + \lambda)$, to fully define the equilibrium, as both $p_s(\tau + \lambda)$ and $Q(\tau + \lambda)$ can then be solved for directly. Finally, these variables, combined with the calibrated scale parameters $B$ and $A$, and an assumed constant

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12 Readers are referred to the original source for further details, especially regarding background on the data and parameter assumptions. While the setup here is identical, the research questions are different. Kotchen (2021) focuses on the incidence between producers and consumers for only the optimal Pigouvian taxes, and there was no consideration of the relationship between the welfare gains and tax revenue.
marginal external cost $\phi$, are all that is needed to solve for $\Delta W(\lambda)$, $\Delta TR(\lambda)$, and $R(\lambda)$ according to equations (1), (2), and (3).

3.2 Data and parameter assumptions

Price and quantity data are needed for establishing initial conditions of the model. These were obtained from the U.S. Energy Information Administration (EIA) for the year 2018 and are reported in Table 1.\footnote{For the broad comparisons being made in this paper, variation from year-to-year over the last decade is relatively inconsequential, except for avoiding years when COVID-19 hit and had substantial effects on energy consumption.} The quantities of all four fuels—natural gas, coal, gasoline, and diesel—are based on annual domestic consumption in the United States. The price of natural gas is the annual average Henry Hub spot price. The price for coal is the annual average cost of coal delivered to electric power plants, which accounts for 93% of all domestic coal consumption in 2018. The prices for gasoline and diesel are the average retail prices in each year.

Table 2 reports the preexisting tax rates and marginal external costs for each fuel. The first column reports the excise equivalent, preexisting taxes taken from Kotchen (2021). These account for existing royalties, severance taxes, and excise taxes, including state and federal taxes on gasoline and diesel. The second column reports marginal external costs due to local pollution, and these health-based estimates are taken from Parry et al. (2014). The third column reports the CO$_2$ intensity of each fuel that is multiplied by the social cost of carbon (SCC) to estimate the marginal external costs due to climate damages. The combined marginal external costs (i.e., local pollution and climate damages) are reported in the remaining columns for different estimates of the SCC that range from $\$50$ to $\$125$ per ton.\footnote{In particular, the combined marginal external cost is equal to $\phi_l + \phi_c$, where $\phi_l$ is the marginal external costs due to local pollution and $\phi_c$ is due to climate damages. The climate damages are calculated based on $\theta_k \times SCC$, where $\theta_k$ is the carbon intensity of fuel $k$, and $SCC$ is the estimate of the SCC.} The $\$25$ increments of the SCC are intended to span the preferred, interim estimate of the U.S. Interagency Working Group on the Social Cost of Greenhouse Gases (2021) and recent estimates of updated values (Carlton and Greenstone 2021).

A literature review informs the point estimates chosen for the supply and demand elasticities. The aim in each case is to select an estimate that represents a long-run
elasticity applicable to the U.S. domestic market. The estimates used here are reported in Table 3. The U.S. Department of the Interior’s (2015) MarketSim model of U.S. energy markets provides a useful resource for some estimates, including those for coal and natural gas. Whenever possible, the estimates are based on the empirical, peer-reviewed literature, and several are the same as those used in the EIA’s National Energy Modeling System (NEMS). In order to account for uncertainty in the estimates and carry out sensitivity analysis, scenarios are considered with low- and high-elasticity estimates, where these cases are consistent with a simultaneous 50-percent decrease or increase in both elasticity estimates. These ranges are reported in brackets in Table 3.

4. Results

This section reports the carbon tax results for each of the four fuels separately, all four fuels combined, and an alternative where the carbon taxes only take effect when they exceed preexisting taxes. Additionally, comparisons are made to other model estimates to provide a sense of external validity of the magnitudes.

4.1 Fuel-specific results

Figure 1 reports the change in welfare, \( \Delta W(\lambda) \), across all four fuels at different levels of the carbon tax. The figure also shows how the results vary substantially with different assumptions about the magnitude of the SCC. This is not surprising because the reduction in the total external cost, which is one component of the welfare change, scales linearly with the SCC. While the results are also sensitive to changes in the elasticities, this variation is less than that for the SCC. Appendix Figure A1 illustrates the results across the range of elasticity scenarios assuming a SCC of $50 per tonne.

The welfare gains from the carbon tax on coal are far greater than that for the other fuels, owing to its large external costs (more on this below). The gains for coal are increasing rapidly with a higher carbon tax up to about $50 per ton, where they start to

\[15\] In the cases of gasoline and diesel, the supply elasticity estimates take account of the upstream and global market for oil. In contrast, the markets for coal and natural gas involve fewer steps on the supply chain and are primarily domestic. See Kotchen (2021) for details.
level off.\footnote{16} While the welfare gain for coal at a $50 carbon tax ranges between $110 and $192 billion, those for natural gas range between $24 and $60 billion. The estimates for gasoline and diesel are quite different. For gasoline, the change is social welfare is negative at all tax rates when the SCC is $50. The reason is that the preexisting excise tax on gasoline already exceeds the marginal external cost at this level of the SCC (56 vs. 53 cents per gallon). This means that imposing the carbon tax over and above the preexisting tax results in a welfare loss.\footnote{17} The same holds for low levels of the tax even with a SCC of $75. It is only when the SCC is greater than $100 that the welfare gain is always positive.\footnote{18} Yet the magnitude remains small, reaching a maximum of $4.7 billion with an SCC of $125 and a carbon tax of $70 per ton. The results for diesel follow a similar pattern, though generally remain positive. The reason is that diesel has a significantly larger externality due to local pollution.\footnote{19}

Figure 2 reports the change in total revenue, $\Delta TR(\lambda)$, at different tax rates, across fuels, and for the three elasticity scenarios (central, low, and high). Total revenue does not depend on the SCC because tax rates are independently set. The low- and high-elasticity scenarios correspond with a simultaneous 50-percent decrease or increase in the central estimate of both the supply and demand elasticities.\footnote{20} The pattern of results illustrates how lower elasticity is associated with greater tax revenue. The magnitudes for the central estimates are roughly similar for both natural gas and gasoline, followed by diesel. The results for coal follow a different pattern. In the low-elasticity scenario, revenue continues to increase with the carbon tax rate. Yet in the central and high-elasticity scenarios, the

\footnote{16} Note that the maximum of any curve does not occur where the carbon tax is equal to the SCC. The reason is twofold: preexisting taxes and the externalities associated with local pollution. It does, however, equal its maximum value when the tax is equal to $\lambda^* = \phi_l + \phi_c - \tau$.

\footnote{17} Later in the paper, we will examine how the results differ if the carbon is only applied when it exceeds the preexisting tax.

\footnote{18} An interesting observation in Appendix Figure A1 is that greater elasticity leads to greater welfare gains when the gains are positive, but it also leads to greater losses when they are negative. This is apparent with a comparison of the results between gasoline and diesel, where the order of the curves is reversed.

\footnote{19} The results for transportation fuels exclude other externalities due to congestion and accidents. While an argument can be made that in the short-run these externalities should be included (Parry et al. 2014; Kotchen 2021), the focus here is on pollution. It is also the case that congestion and accident externalities would remain even as transportation shifts from internal combustion engines to electric vehicles.

\footnote{20} It is useful to note that with constant elasticity of supply and demand the same proportional changes in both elasticities will affect equilibrium quantities but not prices.
results are consistent with a Laffer curve: revenues are initially increasing, reach a maximum, and then begin the fall. In both scenarios, revenue is falling in the tax rate above carbon taxes exceeding $30 per ton.

Figure 3 reports the measure of central interest—the ratio of the change in welfare over the change in tax revenue—for all four fuels and at different tax rates. To limit the proliferation of scenarios to consider, only those for the central estimates of the elasticities are considered, along the range of SCC estimates. Other scenarios based on alternative assumptions are easily constructed from the available data. The four fuels illustrate the range of possibilities about the relative magnitudes captured by the ratio. Those for natural gas range between approximately 0.2 and 1.2. The ratios for coal are substantially larger, beginning above 6 for all levels of the SCC and reaching as high as 43 for a SCC of $125 and a carbon tax of the same value. Coal also differs from the other fuels because the ratio is increasing in the level of the carbon tax, owing to the fact that revenue (the denominator) is increasing at a slower rate (or even decreasing) than the welfare gain (the numerator). The ratios for gasoline and diesel, in contrast, are exceeding low or even negative.

The basic conceptual framework in Section 3 provides a systematic way of understanding why the results differ across fuels, and these differences provide a useful illustration of how ratios might differ in other setting where externality correcting taxes might be applied. Following the general derivation of \( R(\lambda) \) in equation (3), three factors are identified as affecting the magnitude: the market size, the marginal external costs, and the market responsiveness.

Table 4 illustrates the differences across the four fuels. To facilitate comparison, the units of each fuel are converted to British thermal units (Btus).\(^\text{21}\) When measured in terms of Btus at the initial equilibrium, natural gas in the largest market, followed by gasoline, coal, and diesel. Holding other factors constant, a larger market size increases tax revenue and results is a lower ratio (Result 3). However, there are substantial differences in the marginal external costs across fuels, which are shown in Table 4 across fuels and normalized to the same units of Btus. The second row shows the full marginal external

\(^{21}\) Using data form the EIA, these conversions are based on 1,036 Btu per cf of natural gas, 9,592 Btu per pound of coal, 120,286 Btu per gallon of gasoline, and 137,381 Btu per gallon of diesel.
costs (assuming a SCC of $50), and perhaps more relevant for the analysis here, the third row shows the marginal external costs net of the preexisting tax, that is, the uninternalized portion of the externality. Per unit of energy, coal has the highest uninternalized externality, followed by natural gas, diesel, and a negative value for gasoline. All else equal, increases in the uninternalized externality will increase ratios (Result 1). Finally, to facilitate comparison, the market responsiveness is reported as an elasticity, showing the percentage change in Btus given a percentage change in the carbon tax. Note that this elasticity does not equal the supply or demand elasticity, nor is it constant. Hence an illustrative value is reported for a discrete change from a carbon tax of $45 to $50 for all four fuels. The elasticity is the greatest for coal, by a wide margin, and this further explains why coal has a substantially higher ratio (Result 2). Natural gas is also relative elastic compared to gasoline and diesel, and this contributes to its relatively higher ratios.

4.2 Aggregate results

While the fuel-specific analysis illustrates the potential variability of results for externality motivated taxes, we now turn to the aggregated results for a carbon tax applied uniformly across all four fuels. This is, of course, the most efficient way to apply a carbon tax. The results for the change in welfare and the change in tax revenue are simply sums of those shown previously. Graphical summaries of the aggregated results, in parallel with the fuel-specific results for $\Delta W(\lambda)$ and $\Delta TR(\lambda)$ in Figures 1 and 2, are shown in Appendix Figure A2. With a carbon tax of $50 per tonne, the welfare gains range from $132 to $261 billion for SCCs of $50 and $125, respectively. The revenue at the same

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22 When aggregating the results across fuels, it is worth noting that the analysis does not account for cross-price effects. While other studies also employ this simple and transparent approach (e.g., Parry et al. 2014; Davis 2017; Kotchen 2021), cross-price effects could be important in cases where fuels are substitutes (as would hold for coal and natural gas in electricity generation, and gasoline and diesel for transportation), but incorporating these into the analysis in a complete way, even with estimates, is not a simple matter. One would need estimates on the rate of substitution away from fuels and not just between them. Additionally, long-run supply-side responses are another factor not included but that matter. Fully accounting for these different effects would require a general equilibrium model that simultaneously considers interactions among the four different markets for each fuel. These types of considerations are included in models that are discussed in the next
carbon tax level is $152 billion for the central-elasticity estimate, with a range of $129 and $188 billion for the high- and low-elasticity scenarios.

The left-hand side of Figure 4 shows the aggregate ratios at different levels of the SCC and the central-elasticity scenario. The aggregate ratios indicate more of a relative balance between the welfare gains and the tax revenue. In fact, the ratios are greater than 1 at all levels of the SCC and carbon taxes less than $40. For low levels of the carbon tax, the ratios are more centered around 2. These results suggest, rather strikingly, that for low levels of a carbon tax, there is robust evidence that the policy would pass a benefit-cost test even if all of the tax revenue were “burned.” Yet it is worth emphasizing that the tax revenue is not in fact a cost, even though some may view it that way. Returning to the focal point of a $50 carbon tax, the ratio ranges between 0.9 and 1.7 for a SCC of $50 and $125, respectively. Nevertheless, as the illustrated above, these aggregated results mask very different results across fuels.

Let us now consider the question of how much the results change if rather than impose carbon taxes on top of preexisting taxes, the carbon tax only takes effect if it exceeds the level of preexisting taxes. In particular, with a carbon tax of $\lambda$ per tonne, the approach considered thus far has been to impose a tax of $\lambda_k = \theta_k \lambda$ for each fuel $k$, where the fuel-specific carbon intensity is $\theta_k$. The alternative approach now being considered is to apply an effective tax per fuel of

$$\hat{\lambda}_k = \max\{0, \theta_k \lambda - \tau_k\}, \quad (9)$$

where $\tau_k$ is the preexisting tax for fuel $k$. This means that when the carbon tax rate falls below the preexisting tax rate, no additional tax is applied. Moreover, when the carbon tax exceeds the preexisting tax rate, only the difference between the two is applied as a new tax.

Before turning to the impact of implementing (9) on ratios, it is worth noting the possibility for indeterminant effects, in general, on the numerator and denominator. When the combined tax rate exceeds the marginal external costs (i.e., $\tau_k + \theta_k \lambda > \phi$), the alternative approach will increase welfare by not over taxing.\(^{23}\) We saw this condition in

\(^{23}\) Recall that the setup here assumes a constant marginal external cost, and the analysis admits the possibility for a carbon tax set at any level, only one of which is the efficient Pigouvian tax.
the case of gasoline for sufficiently low carbon taxes and values of the SCC. In contrast, when the combined tax is less than the marginal external costs, the alternative approach will decrease welfare by exacerbating the under taxation from an efficiency perspective. As for the tax revenue denominator, whether a decrease in the effective tax rate (for a given carbon tax) increases or decreases tax revenue depends on the side of Laffer curve, and the previous results for coal illustrate the possibility for both. Appendix Figure 3A shows the aggregated results for $\Delta W(\lambda)$ and $\Delta TR(\lambda)$ and the alternative approach. Comparing these to the baseline results in Figure 2A reveals little differences in aggregate welfare, but meaningful changes in tax revenue. For example, the tax revenue for a carbon of $50 with the central-elasticity estimate declines from $152 billion in the baseline scenario to $72 billion with the alternative approach.

The right-hand side of Figure 4 shows aggregate ratios for the alternative approach at different levels of the SCC and for the central-elasticity scenario. The panel is directly comparable to left-hand side for the baseline approach. The use of equation (9) to adjust the carbon tax rates results in substantially higher ratios. With a carbon tax of $50, the ratio ranges between 1.8 and 3.5 for the a SCC of $50 and $125, which is up from 0.9 to 1.7 for the baseline approach. And for lower carbon taxes many of the ratios imply that the welfare gain is between 3 and 5 times the size of the tax revenue. The figure also shows the kink at a carbon tax of $65, which is the level at which the effective tax rate for gasoline and diesel become greater than the preexisting tax for both fuels.

4.3 External validity

The final question to consider in this section is the extent to which the simple and transparent model used here has external validity in terms of the magnitudes it produces. There are, of course, more complicated models that analyze various topics related to carbon taxes. The comparisons made here are to a meta-analysis across 11 different energy and economy models included in the Stanford Energy Modeling Forum exercise 32 (EMF 32). Barron et al. (2018) provide a set of policy insights across models for implementation of different carbon tax scenarios. Two sets of results they report are the CO$_2$ emission
reductions and tax revenues for different carbon tax policies, and these can be compared to the results here as a check of external validity.

A summary of the results across all 11 models is reported on the left-hand side of the two panels in Figure 5. For example, in the top panel, the average emission reduction across EMF 32 models is 18 and 29 percent below the baseline for carbon taxes of $25 and $50, respectively. Also reported are the minimum and maximum values across models. The right-hand side shows comparable results of emissions reductions for the simpler model used in the present paper, and the magnitudes are quite similar. For the central-elasticity estimate, the reductions are 25 and 35 percent for carbon taxes of $25 and $50, respectively. The magnitudes of the low- and high-elasticity scenarios also correspond well with the min and max results of the EMF models. The bottom panel of Figure 5 compares results for annual tax revenue. Here again the magnitudes averaged across the 11 EMF models and those produced here are quite similar. For the $25 carbon tax scenario, the EMF average tax revenue of $103 billion compares to $95 billion here. And for the $50 carbon tax scenario, the respective magnitudes are $170 billion and $158 billion.

The overall conclusion, based on these comparisons, is that the very simple and transparent model employed in this paper, which can readily accommodate alternative assumptions, produces similar results on the impacts of implementing carbon taxes in the U.S. economy. The primary aim has been to illustrate the different possibilities for the ratio of welfare gains to tax revenue, both across fuels and in aggregate; yet these comparative results to the EMF meta-analysis provide a degree of external validity for interpreting the

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24 Specifically, the carbon tax scenarios in Barron et al. (2018) that are referenced here are for $25 and $50 that increase 1 percent per year. Moreover, the percentage decrease in emissions from the baseline is the cumulative effects over the years 2020 through 2030.

25 To produce results for taxes of similar magnitude to those in the EMF meta-analysis, the $25 and $50 scenarios used here are the average results based on an assumed carbon tax of $25 and $30 and of $50 and $55. The averaging of results at these different prices is intended to come closer to the 1% increase over 10 years that was assumed in the EMF analyses.

26 The revenue results, which are consistent with lump-sum recycling, are taken from Table 2 in Barron et al. (2018) with two adjustments. The first is conversion to 2018 dollars using the GDP deflater. The second is to adjust the gross tax revenue to reflect an estimate of the net revenue, which accounts for reductions in tax revenue from other sources. The adjustment is made using the average “haircut” across models for each scenario as reported in Table 5 of McFarland et al. (2018). In particular, the haircut is 24 percent for the $25 scenario and 27 percent for the $50 scenario. The EMF revenue results are reported for 2021 through 2030, and the annual estimate is obtained by simply taking the average.
magnitudes as well. Indeed, the results are well within the bounds established in the literature by more detailed and computationally intensive approaches.

7. Discussion and conclusion

There are two central aims of this paper: (a) to argue that reporting of the ratio of welfare gains to tax revenue should be standard protocol in economic analyses of externality correcting taxes, and (b) to illustrate the range of potential results with an application to carbon taxes on fossil fuels in the United States.

7.1 The case for ratios

Economists rarely hesitate to recommend Pigouvian taxes as a preferred approach for addressing externalities. Even when taxing at the optimal level is not feasible, using taxes to internalize some portion of the external costs is considered advantageous because of the associated efficiency gain. But these recommendations rely on a critical assumption that tax revenue is welfare neutral. Is this assumption always reasonable? While political debates often revolve around this question, shouldn’t it matter if the tax revenue is orders of magnitude larger than the welfare gain or perhaps only a small fraction? The fundamental assertion of this paper is that the ratio of the welfare gain to tax revenue should be an object of interest when analyzing and advocating for or against an externality correcting tax.

There are several reasons why consideration of the proportional magnitudes of welfare gains to tax revenue is compelling for externality correcting taxes. The first is straightforward positive political economy. While economists advance Pigouvian type taxes with the aim of correcting a market failure, concerns about government failure often drive opposition.

27 In other words, economists typically focus on the efficiency gains,

27 Although not the focus of this paper, a political economy framing might consider an objective function where tax revenue is not welfare neutral according to some parametrization $0 \leq \kappa \leq 1$, where $\kappa$ greater than zero represents the costs of administration and compliance, or even an ideological aversion to raising government revenue. It is therefore like a discount factor on the tax revenue. In this case, we might expect an optimized new tax level to satisfy $\max_{\lambda} \{\Delta W(\lambda) - \kappa \Delta TR(\lambda)\}$, where the standard solution is based on the assumption that $\kappa = 0$. Alternatively, for any level of $\lambda$, we can divide the maximand by $\Delta TR(\lambda)$ to get the
whereas the hurdle to implementation if often the raising of tax revenue. The ratio of these two magnitudes provides a sense of proportionality between these two sets of interests and may therefore help to evaluate potential feasibility, which will also depend on whether there is an interest or need to raise revenue (Barthold 1994).

A second reason relies only on the efficiency criterion. Even Pigou’s (1947) formulation recognizes administration and compliance costs. And it is reasonable to assume that any such costs, which could also include corruption, will scale in proportion to the quantity of the harmful activity or the tax revenue (Polinsky and Shavell 1982). Whether the policy promotes efficiency might then hinge on whether the ratio of the welfare gain to the tax revenue is something like 20:1 or 1:20. Nevertheless, the information to make such a calculation is typically not even reported in economic analyses, nor does the way that economists recommend Pigouvian type taxes acknowledge that such proportions might matter.

A third reason is because of increasing concern about the distributonal consequences of policy interventions. As noted previously, economists have begun paying more attention to the different ways in which revenue generated from externality correcting taxes can be redistributed, especially in the context of economy-wide carbon taxes. Without needing to take a stand on how revenue should be redistributed to accomplish equity objectives, the ratio of the welfare gain to tax revenue clarifies how important decisions about the aims of tax revenue might be. When the ratios are lower, and argument can be made that its increasingly important to make the aims of the tax revenue an explicit part of the policy proposal, rather than assuming this aspect away. Doing so may also help to minimize the potential for regulatory capture of the revenue after implementation and aid in the comparison of distributional outcomes across a set of candidate policy instruments.

Finally, the ratio of the welfare gain to tax revenue for an externality correcting tax is closely related to other concepts that are well established in the public economics literature. For a small change in tax policy, the MEB is a compensated (Hicksian) measure condition \( R(\lambda) - \kappa \), which tell us whether the ratio of welfare gain to tax revenue is big enough to compensate for the implied discount factor on the revenue itself.
of the change in welfare over the tax revenue, which in principle can be positive or negative (Ballard and Fullerton 1992). The MVPF provides a similar measure that differs because it is uncompensated (Marshallian) and less prescriptive about how the government budget must be closed (Hendren 2016; Hendren and Sprung-Keyser 2020; Finkelstein and Hendren 2020). The ratio described in this paper has the same virtue of the MVPF because the linkage to observed market behavior is more direct. Moreover, it generalizes the concept to more explicitly account for externality correcting taxes where welfare gains (rather the losses) are associated with raising tax revenue. In cases where there is a need to raise tax revenue, therefore, the ratio can help steer the tax system towards externality-causing goods and services that produce the greatest welfare gains.

7.2 Application to carbon taxes

The simple theory developed in this paper shows how the ratio of the welfare gain to tax revenue will depend on three fundamentals: the size of the marginal external costs, the market size, and the market responsiveness to the tax. The range of potential results are illustrated across fossil fuels when considering implementation of a carbon tax in the United States. The ratios are high for coal because of its large external costs and relatively large market elasticity to implementation of a tax. The ratios are low (and even negative) for gasoline and diesel because of the large market sizes, relative inelasticity, and substantial preexisting tax rates. Natural gas provides an intermediate case with ratios indicating a more proportional balance between welfare gains and tax revenue.

The most efficient policy is, of course, to apply a uniform carbon tax across fuels and to account for preexisting taxes such that an overall tax rate is equal to the marginal external costs at the efficient quantity. Doing this implies ratios that range between 1.8 and 1.4 for the central-elasticity estimates and estimates of the SCC that range between $50 and $125 for tonne (see the right panel of Figure 4). These ratios imply the implementing a carbon tax is predicted to generate between $1.80 and $1.40 of welfare gains for each dollar of tax revenue raised. While decidedly not a benefit-cost ratio, these results do suggest that imposing an efficient tax would not only pass a benefit-cost test, it would do so even if all the tax revenue were “burned” and not used to generate additional social
benefits. The high ratios also suggest that carbon taxes are likely to be efficient even if one were to account for reasonable administrative and compliance costs.

While the carbon tax estimates generated here employ the simple and transparent model first used in Kotchen (2021), they produce estimates very close to those of more detailed energy-economy models of the United States (Barron et al. 2018). The empirical results thus have a relatively high degree of externality validity, and the approach can readily accommodate alternative assumptions about external costs, demand and supply elasticities, and policies to consider. Finally, it is worth noting that the comparisons for external validity were only possible because the other models reported information about tax revenue, which is far from standard in economic analyses of externality correcting taxes. Hence this paper concludes with a general appeal for economists: reporting on the ratio of efficiency gains and tax revenue is useful when analyzing and advocating for externality correcting taxes, but even short of that, reporting the magnitude of tax revenue should be standard practice. When analyzing externality correcting taxes, regardless of the application, for purposes of advancing realistic policy proposals, it is time for economists to abandon the practice of ignoring the magnitude of tax revenue based on the assumption of its welfare neutrality.
References


**Table 1:** Price and quantity data for natural gas, coal, gasoline, and diesel

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Price</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural gas (Henry Hub spot)</td>
<td>$3.26 per 1000 cf</td>
<td>30,075 billion cf</td>
</tr>
<tr>
<td>Coal (delivered for electric power)</td>
<td>$39.63 per short ton</td>
<td>688 million short tons</td>
</tr>
<tr>
<td>Gasoline (retail)</td>
<td>$2.73 per gallon</td>
<td>143 billion gallons</td>
</tr>
<tr>
<td>Diesel (retail)</td>
<td>$3.18 per gallon</td>
<td>64 billion gallons</td>
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</table>

Notes: All data obtained from the EIA for 2018. See the main text for details.

**Table 2:** Preexisting taxes and marginal external costs by fuel

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Preexisting tax</th>
<th>Local pollution (mt)</th>
<th>CO₂ intensity (mt)</th>
<th>Combined marginal external costs</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>$0.16</td>
<td>$1.42</td>
<td>0.0606</td>
<td>SCC $50 $5.97 $7.48 $9.00</td>
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<tr>
<td>Natural Gas (per 1000 cf)</td>
<td>$2.72</td>
<td>$127.45</td>
<td>1.9041</td>
<td>SCC $222.66 $270.26 $317.86 $365.46</td>
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<tr>
<td>Coal (per short ton)</td>
<td>$0.56</td>
<td>$0.09</td>
<td>0.0087</td>
<td>SCC $0.53 $0.74 $0.96 $1.18</td>
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<tr>
<td>Gasoline (per gallon)</td>
<td>$0.63</td>
<td>$0.70</td>
<td>0.0097</td>
<td>SCC $1.19 $1.43 $1.67 $1.91</td>
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<tr>
<td>Diesel (per gallon)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes: See the main text and Kotchen (2021) for details.
**Table 3:** Demand and supply elasticity estimates

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Demand</th>
<th>Supply</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas</td>
<td>-0.55</td>
<td>1.6</td>
</tr>
<tr>
<td></td>
<td>[-0.28, -0.83]</td>
<td>[0.80, 2.40]</td>
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<tr>
<td>Coal</td>
<td>-1.75</td>
<td>1.9</td>
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<tr>
<td></td>
<td>[-0.88, -2.63]</td>
<td>[0.95, 2.85]</td>
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<td>Gasoline</td>
<td>-0.63</td>
<td>2.0</td>
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<td>[-0.32, -0.85]</td>
<td>[1.00, 3.00]</td>
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<tr>
<td>Diesel</td>
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<td>[-0.29, -0.87]</td>
<td>[1.00, 3.00]</td>
</tr>
</tbody>
</table>

Notes: See the main text for details. Numbers in brackets are the range for a 50-percent decrease and increase in the estimate.

**Table 4:** The market size, marginal externality, and market responsiveness for each fuel

<table>
<thead>
<tr>
<th></th>
<th>Natural gas</th>
<th>Coal</th>
<th>Gasoline</th>
<th>Diesel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Market size at $\lambda = 0$ (Trillion Btus)</td>
<td>31,158</td>
<td>13,199</td>
<td>17,201</td>
<td>8,792</td>
</tr>
<tr>
<td>Marginal externality ($s per million Btu)</td>
<td>$4.30</td>
<td>$11.61</td>
<td>$4.41</td>
<td>$8.66</td>
</tr>
<tr>
<td>Marginal externality net of preexisting tax ($s per million Btu)</td>
<td>$4.12</td>
<td>$11.49</td>
<td>-$0.26</td>
<td>$3.98</td>
</tr>
<tr>
<td>Market elasticity to carbon tax (from a carbon tax of $45 to $50)</td>
<td>-0.23</td>
<td>-1.15</td>
<td>-0.07</td>
<td>-0.06</td>
</tr>
</tbody>
</table>

Notes: The market size and marginal external costs are reported in term of Btus. The latter is based on a SCC of $50, and the market elasticity, as measure of the market responsiveness, is based on the central-elasticity estimates and a change in the carbon tax from $45 to $50 per tonne. See the main text for details on unit conversions.
**Figure 1:** Annual change in welfare, $\Delta W(\lambda)$, for all four fuels at different carbon tax rates, assumptions about the social cost of carbon, and the central-elasticity estimates. The scenarios of SCC50, SCC75, SCC100, and SCC125 correspond to the SCC at $50$, $75$, $100$, and $125$. 
Figure 2: Change in tax revenue, $\Delta TR(\lambda)$, for all four fuels at different carbon tax rates and assumptions about the market elasticities. The scenarios of central, low and high elasticity correspond to the central estimates, a 50-percent decrease in both the supply and demand elasticities, and a 50-percent increase in both elasticities. See Table 3 for the specific estimates employed.
Figure 3: The ratio, $R(\lambda)$, for all four fuels at different carbon tax rates, assumptions about the social cost of carbon, and the central-elasticity estimates. The scenarios of SCC50, SCC75, SCC100, and SCC125 correspond to the SCC at $50, $75, $100, and $125.
Figure 4: The ratio, $R(\lambda)$, for all fuels combined at different carbon tax rates, assumptions about the social cost of carbon, and the central-elasticity estimates. The left-hand side is for the baseline case where the carbon tax is imposed over and above preexisting taxes. The right-hand side is for the alternative case where carbon tax only takes effect if it exceeds the preexisting tax. The scenarios of SCC50, SCC75, SCC100, and SCC125 correspond to the SCC at $50, 75, 100, \text{ and } 125$. 
Figure 5: Comparison of results generated here with those across models from the EMF 32 study on U.S. carbon tax scenarios. The top panel compares the percentage reduction in CO$_2$ emissions from a no tax baseline, and the bottom panel compare estimates of the annual tax revenue. Details on how comparisons where made within the $25 and $50 tax scenarios are reported in the main text.
Appendix figures

**Figure A1**: Annual change in welfare, $\Delta W(\lambda)$, for all four fuels at different carbon tax rates, a social cost of carbon equal to $50$, and assumptions about the market elasticity. The scenarios of central, low and high elasticity correspond to the central estimates, a 50-percent decrease in both the supply and demand elasticities, and a 50-percent increase in both elasticities. See Table 3 for the specific estimates employed.
Figure A2: The left panel shows the change in welfare, $\Delta W(\lambda)$, aggregated across fuels at different carbon tax rates, assumptions about the social cost of carbon, and the central-elasticity estimates. The scenarios of SCC50, SCC75, SCC100, and SCC125 correspond to the SCC at $50, $75, $100, and $125. The right panel shows tax revenue, $\Delta TR(\lambda)$, aggregated across fuels at different carbon tax rates and assumptions about the market elasticities. The scenarios of central, low and high elasticity correspond to the central estimates, a 50-percent decrease in both the supply and demand elasticities, and a 50-percent increase in both elasticities. See Table 3 for the specific estimates employed.
Figure A3: The graphs correspond with the alternative approach whereby carbon tax are only applied for each fuel if the rate exceeds the preexisting tax, as specified in equation (9). As with Figure A2, the left panel shows the change in welfare, $\Delta W(\lambda)$, aggregated across fuels at different carbon tax rates, assumptions about the social cost of carbon, and the central-elasticity estimates. The right panel shows tax revenue, $\Delta TR(\lambda)$, aggregated across fuels at different carbon tax rates and assumptions about the market elasticities.